Doppler Sonar Observations of the Kuroshio in ASIAEX 2000

Robert Pinkel
Marine Physical Laboratory
Scripps Institution of Oceanography
La Jolla California 92093-0213
Phone: (858) 534-2056 fax: (858) 534-7132 email: rpinkel@ucsd.edu

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LONG-TERM GOALS

To gain a more complete understanding of ocean dynamical processes, particularly at fine-scale, through intercomparison of high, mid- and low-latitude observations, both near the sea surface, in the main thermocline, and near the sea floor.

OBJECTIVES

To identify the phenomena involved in the cascade of energy from mesoscales to turbulent scales. To quantify the relationship between fine-scale background conditions and the occurrence of microscale breaking.

APPROACH

Progress is effected through a steady-state cycle of instrument development, field observation and data analysis. The primary instruments employed include Doppler sonar and profiling CTD's. Generically, our instruments produce information which is quasi-continuous in space and time. Measurements typically span two decades in the wavenumber domain. This broad band space-time coverage enables the investigation of multi-scale interactions.

WORK COMPLETED

We have participated in the first phase of ASIAEX (April-May 2000) in the East China Sea. Using the dual frequency Hydrographic Doppler Sonar System on the R.V. Roger Revelle, profiles of ocean currents were obtained to 700 m depth with 15 m vertical resolution and to 250 m depth with 3 m vertical resolution (Figure 1). In the course of the experiment, several transects of the Kuroshio were performed. The combined sonar and CTD data render a rather complete spatial picture of the hydrographic fields.

A series of very energetic shear layers were found (by graduate student Luc Rainville) to underlie the base of the Kuroshio. These slope downward offshore and have horizontal coherence scales of 30-50 km. The observed slopes slightly exceed the slope of isopycnal surfaces, suggesting that they are waves with a near-inertial intrinsic frequency. The shear associated with these waves exceeds the geostrophic shear of the Kuroshio.

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14. ABSTRACT
To gain a more complete understanding of ocean dynamical processes, particularly at finescale through intercomparison of high, mid- and low-latitude observations, both near the sea surface in the main thermocline, and near the sea floor.

15. SUBJECT TERMS

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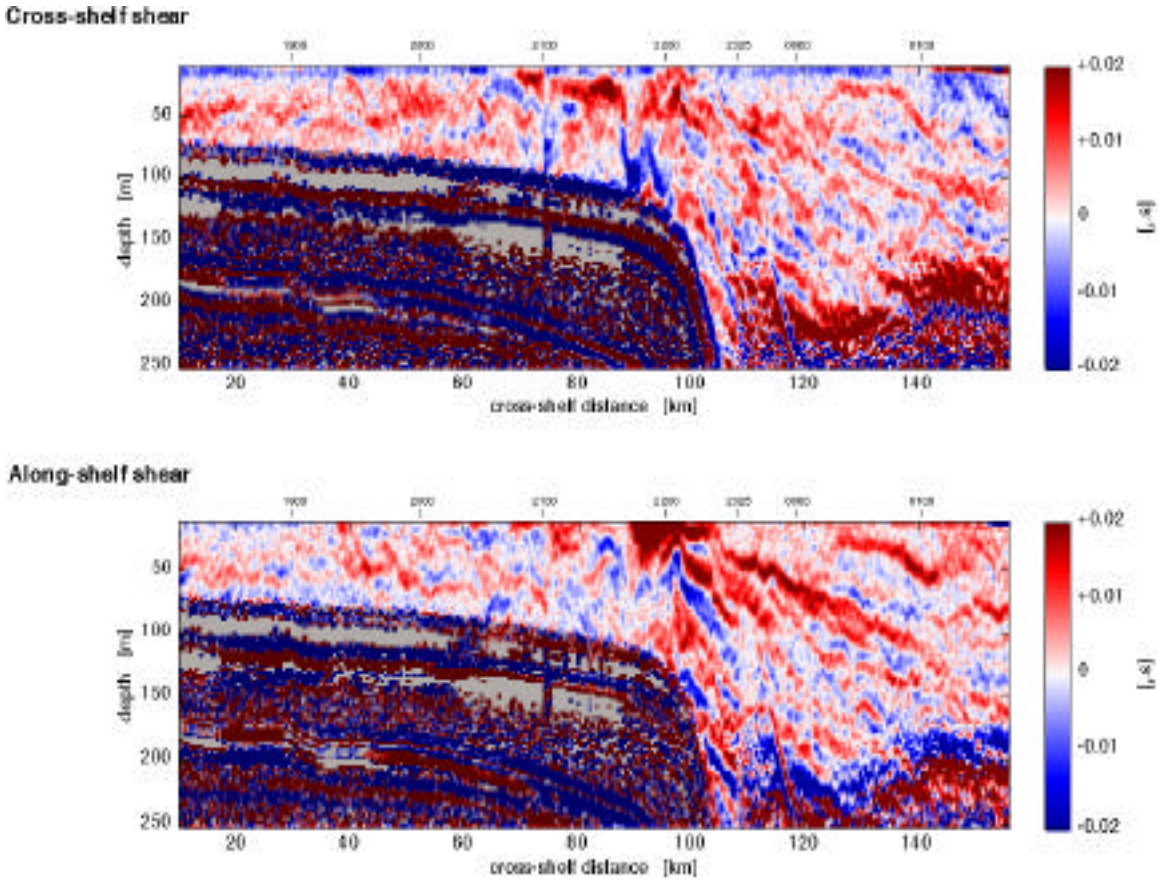

Figure 1.Maps of vertical shear measured by the High Resolution Sonar (140kHz) near the shelf break on April 17, 2000. For this line, the R/V Revelle was going from the continental shelf to deep water. Time (UTC) is marked on the upper axis of each panel. The bottom topography is indicated by the darker region. The along-shelf current (into the page) is dominated by the Kuroshio, with the front located at the shelf break, at a cross-self distance of about 95 km.

Plans to revisit the area on the R/V Melville in ASIAEX II (May-June 2001) were not realized. Given our extreme interest in the processes at this site, an impromptu cruise of opportunity was conducted in May 2002 as the R/V Melville transited from the Marshall Islands to Japan. Luc Rainville organized an all-student team to ride the Melville, conducting ADCP, lowered ADCP, and CTD profiling across the Kuroshio, slightly north of the original ASIAEX site. Approximately two days of ship time were made available for the survey.

University of California funds were used to support the added ship time and the students travel expenses. Instrument preparation expenses were paid for under this program.

RESULTS

Unfortunately, the R/V Revelle was not available for the 2002 “Kyushu” Cruise. Current measurements were obtained with the Melville’s 150 kHz ADCP and with a 150 Hz lowered Doppler sonar/CTD. The Kyushu measurements again revealed strong shears both shoreward and below the Kuroshio. During a 30 hour time series collected in the core of the Kuroshio (30°45´N, 131°45´E), clear evidence for the vertical propagation of these shear layers in seen (Figure 2), establishing the wave-like nature of the phenomenon. There is some success (Figure 2b,c) in relating the vertical

direction of wave propagation to the instantaneous sense of shear rotation with depth. This suggests that a large fraction of the observed shear variance is associated with waves of near-inertial intrinsic frequency.

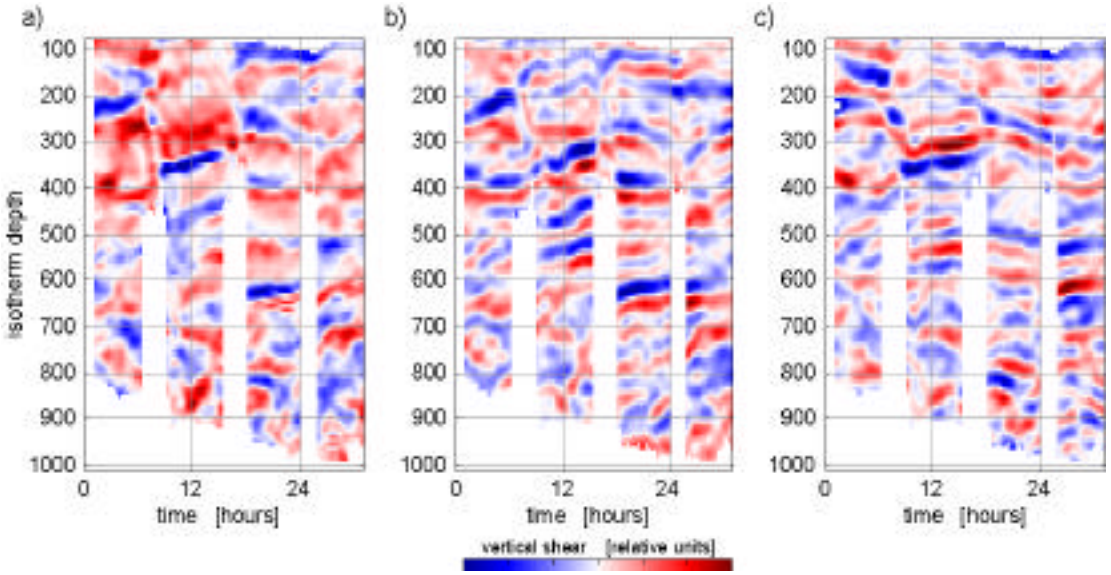

Figure 2.Depth-time maps of cross-shelf vertical shear for the 30-h yoyo station. a) Cross-shelf shear fluctuations, normalized by the buoyancy frequency are presented in an isopycnal following frame. The shear components rotating CW, (b), and CCW, (c), with depth are separated by doing an inverse Fourier transform on the positive and negative wavenumbers of the rotary fourier coefficients, respectively. While lateral advection affects the apparent time response, there is a dominance of upward phase propagation in (b) and downwards in (c). (From Rainville and Pinkel, submitted to JPO).

If this is the case, one might expect the propagation of these waves to be strongly affected by variation in the vertical component of background ocean vorticity associated with the Kuroshio. Kunze, 1985 has suggested that the relevant governing parameter is $f_{eff} = f + \zeta$, where ζ is the vertical component of background vorticity. From a 2002 transect of the Kuroshio (Figure 3), maps of along-shelf velocity, shear and f_{eff} are obtained. Vertical profiles of temperature gradient, an index of the non-linear vertical straining of the thermocline, are over-plotted on the map of f_{eff}. There is an apparent co-relation between "stepiness" in the temperature profiles and local extrema in the f_{eff} field. Such a relationship can be explained by a variety of refractive phenomena. It is unfortunate that there was insufficient time to make a more detailed profiling survey. In Figure 3c the vertically averaged (20-400m) shear variance is compared with the square of the 20-400m mean shear and the geostrophic shear squared, as a function of offshore distance. While the geostrophic and depth-mean shears clearly reflect the presence of the Kuroshio, the overall shear varience grows more or less monotonically with onshore distance. Values exceed ten times the geostrophic shear^2 inshore of the Kuroshio. We conjecture that the Kuroshio serves as a "vorticity wall" trapping shelf-slope generated waves on its inshore side.

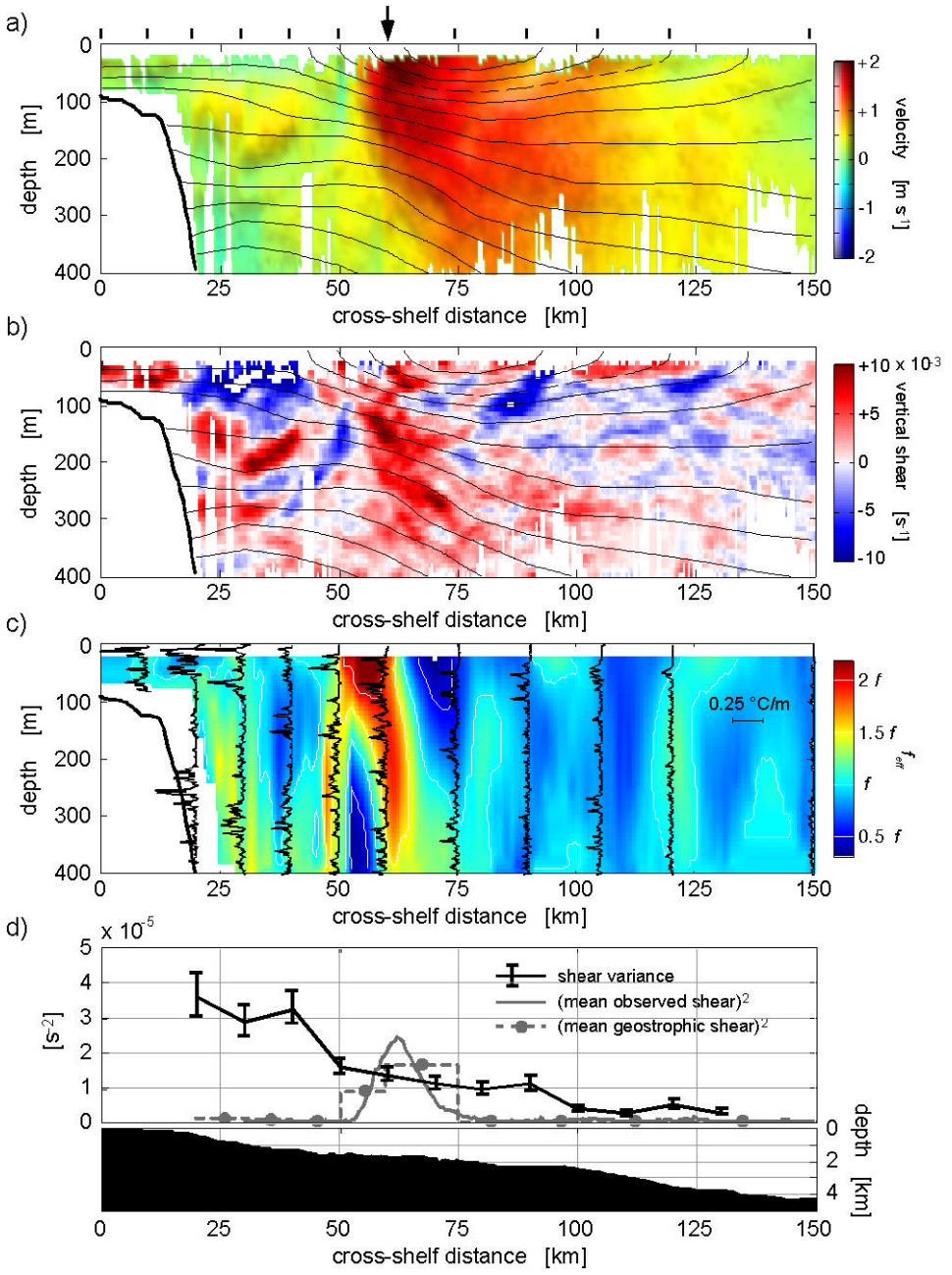

Figure 3.A section across the Kuroshio during the Kyushu cruise showing the along-shelf velocity, (a), and the along-shelf vertical shear, (b). Isopycnals are shown as black contours and the stations locations are indicated on the top panel (arrow shows yoyo station). (c) The effective inertial frequency as a function of depth and cross-shelf distance. The temperature gradient profile at the location of each station is overplotted in black. (d) The depth-averaged shear variance (20 to 400-m depth range, $l_z \geq 50$ m). is plotted vs. distance (black). Shipboard ADCP data are used. The solid gray line is the square of the observed mean along-shelf shear, and the dotted gray line is the square of the 25-400-m depth-averaged geostrophic shear (computed between pairs of stations). Seafloor depth is indicated in the lower panel. (From Rainville and Pinkel, submitted to JPO).

IMPACT/APPLICATIONS

These organized motions must greatly influence dissipative processes at the Kuroshio Front. In turn, they must be strongly influenced by the meandering nature of the Kuroshio and its interaction with the continental shelf. Present numerical modeling efforts relate local dissipation to local geostropic shear. This is clearly inappropriate in regions like the Kuroshio, where the shear field is dominated by near inertial waves. A detailed investigation of the geography of dissipation within a western boundary current is warranted.

The highly coherent, anisotropic, step-like features induced in the density field by the straining of these layers will have a profound influence on the propagation of sound, an influence of relevance to naval operations. Given the strong acoustic signature that these layers must have, an experiment focused on their study might well make use of acoustic techniques.

TRANSITIONS

The Hydrographic Doppler Sonar System on the R.V. Revelle (funded primarily by NSF and the University of California) will be kept in continuous operation for future users of the ship. It is suggested that other ships in the US research fleet might benefit from similar systems.

RELATED PROJECTS

The shear data obtained in ASIAEX will be merged with the CTD data collected by Steve Ramp (NPGS) to produces a comprehensive picture of the region. Observations of wave phenomena at the shelf break and on the shelf will be applied to models of acoustic propagation in the region by Jim Lynch, Tim Duda, and John Colosi of Woods Hole.

REFERENCES

Alford, M.H., R. Pinkel, 2000: Observations of overturning in the thermocline: The context of ocean mixing. J. Phys. Oceanogr., 30, 805-832

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PUBLICATIONS

A paper describing the Asiaex results is in review at JPO.